PLANTS WHICH REQUIRE SODIUM

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(WITH TWO FIGURES)

It has long been customary to regard sodium as necessary for animals but not for plants. In the light of our present knowledge of the rôle of inorganic salts, it is clear that this distinction between plants and animals is of fundamental importance, if it be true in all cases; but if exceptions occur, its significance largely disappears. The experiments which are described here were undertaken in order to learn whether there are cases in which sodium is as necessary for plants as for animals.

One flowering plant was studied, and several genera of algae, among which were representatives of the green, brown, and red algae. The investigation included species from the Atlantic and the Pacific.

The method consisted in replacing the NaCl of the sea water by one of the following substances in turn: NH_4Cl, CsCl, RbCl, LiCl, KCl, $MgCl_2$, $CaCl_2$, $SrCl_2$, $BaCl_2$,[1] $MgSO_4$, and K_2SO_4. After some preliminary experiments it became evident that the best substitutes for Na are Ca, Mg, and K. An attempt was then made to get better results by using these as substitutes for NaCl in the following combinations (the figures refer to molecular proportions as shown in the table): 500 $MgCl_2$+500 $CaCl_2$, 250 $MgCl_2$+750 $CaCl_2$, 500 KCl+500 $CaCl_2$, 667 KCl+333 $CaCl_2$, 910 KCl+91 $CaCl_2$.

All the salts were carefully tested before using and were recrystallized when necessary. The water was twice distilled from glass without the use of rubber or cork stoppers; in place of these a plug of absorbent cotton was employed. The water thus produced was not toxic to such test objects as *Spirogyra* and the root-hairs of *Gypsophila*, and its quality was further shown by the fact

[1] The introduction of $BaCl_2$ and $SrCl_2$ produced precipitates of $BaSO_4$ and $SrSO_4$ which were allowed to remain at the bottom of the dish during the experiment.

that *Phyllospadix* after being transferred directly to it from the sea water lived for 47 days.

All the solutions were made neutral to phenolphthalein before being used. The material was placed in glass dishes in diffused light and kept covered to exclude dust.

The average temperature in experiments with the Pacific species was about 20° C. and was not subject to much fluctuation. In the experiments on the Atlantic coast the jars containing the plants were partly submerged in running water during the entire period of the experiment, and the temperature did not vary far from 20° C.

It is very important to avoid an excessive amount of light. The optimum must be determined in each case by experiment, but is usually less for algae than for flowering plants.

The plants lived much longer in sea water (whether natural or artificial) than in any solution in which the sodium of the sea water was replaced by some other substance. The best substitutes for Na are Ca, Mg, and K. The accompanying table shows the length of life of the plants in solutions made up with these substitutes. It is evident that we cannot say that one of these substitutes is better than another unless we also specify what plant is being experimented on. With one plant Ca fills the place of Na better than anything else, while with another K proves better; with still another Mg is better; and in still other cases combinations (for example, Mg+Ca or K+Ca) are advantageous.

Great diversity was observed among the different species in respect to their behavior toward the other substances which were employed as substitutes for NaCl. To *Phyllospadix* the substitution of Li in place of Na is much more injurious than that of Rb, but just the opposite is true of *Ulva*, while the other plants seem to be injured about as much by Li as by Rb. Similar diversities are found in the behavior of the plants toward the other salts. These facts are important in so far as they give us a clue to the specific action of salts in life processes; this subject will receive further discussion in a subsequent paper.

All the different plants agree in showing that the replacement of Na by Ca, Mg, or K, all of which are present in considerable quan-

tity in sea water, is less injurious than the introduction of such substances as NH_4, Ba, Sr, Cs, Rb, and Li.

Some attempts were made to obtain a better solution by combinations of $MgCl_2+MgSO_4+KCl+CaCl_2$ in the proportions in which they occur in sea water and also in various proportions other than those mentioned above. So far, however, no combi-

TABLE SHOWING DURATION OF LIFE IN DAYS

Culture solution	Phyllospadix Torreyi	Ulva lactuca	Porphyra perforata	Porphyra naiadum	Egregia Menziesii	Nitophyllum multilobum	Chondrus crispus
Tap water	49	23	4	..	4	..	12
Distilled water	47	27	4	..	4	..	8
Sea water	102+	134+	50+	15+	17+	18+	90+
Artificial sea water— Stock solution*							
78 cc. $MgCl_2$ .375 M 38 cc. $MgSO_4$ .375 M 22 cc. KCl .375 M 10 cc. $CaCl_2$ .375 M +1000 cc. NaCl .375 M	102+	134+	50+	15+	17+	18+	90+
Stock solution+ 1000 cc. $CaCl_2$ .375 M	56	52	16	3	5	2	12
Stock solution+ 1000 cc. $MgCl_2$ .375 M	52	52	10	2	5	2	30
Stock solution+ 1000 cc. KCl .375 M	73	21	8	1	2	1	12
Stock solution+ 1000 cc. $MgSO_4$ .375 M	47	47	8	$\frac{3}{4}$	2	1	12
Stock solution+ 1000 cc. K_2SO_4 .1875 M	60	21	6	1	2	1	..
Stock solution+ { 500 cc. $MgCl_2$ .375 M 500 cc. $CaCl_2$ .375 M	52	89	10	2	6	2	12
Stock solution+ { 250 cc. $MgCl_2$ .375 M 750 cc. $CaCl_2$ .375 M	52	52	10	2	$4\frac{1}{6}$	2	15
Stock solution+ { 500 cc. KCl .375 M 500 cc. $CaCl_2$ .375 M	47	28	10	1	3	2	17
Stock solution+ { 667 cc. KCl .375 M 333 cc. $CaCl_2$ .375 M	73	21	10	1	3	1	12
Stock solution+ { 910 cc. KCl .375 M 91 cc. $CaCl_2$ .375 M	66	28	6	$\frac{3}{4}$	2	1	8

The (+) sign denotes that the plants were alive when the experiment was discontinued.
* It should be noted that the stock solution contains no NaCl.

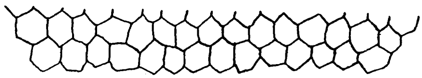
nation has been found which is decidedly better than those given in the table.

Similar results were obtained with *Gigartina*, *Ptilota*, *Iridaea*, and *Prionitis*.

Very much more striking results were obtained when experiments on regeneration were made in these solutions. Pieces of

Ulva were cut into strips and placed in the solutions. In sea water and in artificial sea water the cells along the cut edges grew and divided repeatedly, but this did not occur in any of the solutions which lacked sodium (figs. 1 and 2).

In view of these results we may conclude that for the plants studied sodium is as necessary as for animals. That its function is not merely to maintain osmotic pressure is evident from the fact that if sodium chloride be replaced by an osmotically equivalent amount of cane sugar the plants quickly die. That sodium is



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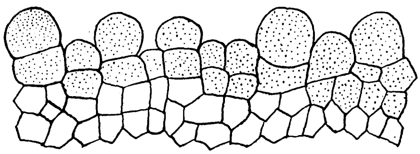

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FIGS. 1 and 2.—Fig. 1, portion of a frond of *Ulva* cut along one edge for experiments on regeneration; fig. 2, regeneration along the cut edge of a frond of *Ulva;* the newly formed cells are dotted; this regeneration takes place only in solutions containing sodium.

needed to antagonize the toxic action of the other salts in the solution is clear from these and previous experiments.[2] Whether sodium is needed for nutrient purposes must be decided by further experiments.

Since this investigation was begun, papers by RICHTER[3] have appeared in which he states that sodium is necessary for the nutrition of certain marine diatoms but not for that of other marine algae. Aside from diatoms his experiments seem to have been confined to a single unicellular alga. Many unicellular forms are so exceptional in their behavior that it would be unwise to draw general conclusions from experiments conducted on them alone. RICHTER states that while they grow in the absence of NaCl, they

[2] OSTERHOUT, BOT. GAZ. **42**:127. 1906.

[3] RICHTER, Sitzungsb. Kais. Akad. Wien **118**:1337. 1909.

grow much better when it is present. In his experiments only Na, K, Mg, and Ca were used, and the proportions employed were not those which exist in sea water.

Summary

Sodium is as necessary for the marine plants studied as for animals; its replacement in sea water by NH_4, Ca, Mg, K, Ba, Sr, Cs, Rb, or Li is decidedly injurious.

The best substitutes for Na are the other kations which predominate in the sea water, Mg, Ca, and K.

The behavior of various species toward certain salts indicates that each of these salts has a specific action on life processes.

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